Conceptual problems in phenomenological interpretation in searches for variation of constants & violation of various invariances

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Abstract

At present a number of current or proposed experiments are directed towards a search for a 'new physics' by detecting variations of fundamental physical constants or violations of certain basic symmetries. Various problems related to the phenomenology of such experiments are considered here.

1 Introduction

Progress in precision studies and shortage of data on possible extension of the Standard Model of weak, electromagnetic and strong interactions have produced a situation when a number of experiments to search for so-called 'new physics' have been performed or planned in atomic physics. Among such experiments are a search for an electric dipole moment of an electron and a neutron, search for variation of fundamental constants and violation of Lorentz invariance etc.

While a number of experiments are designed to check a particular theory, the others have aimed to look for 'new physics' in a 'model-independent way'. Most of such experiments involve various constraints even within a

phenomenological interpretation. Such conceptual problems of new physics in phenomenological interpretation are considered in this note.

An example of such a problem is a relation of possible time or space variation of fundamental constants and a basic relativistic principle of local position/time invariance (LPI/LTI)[1]. Some scientists consider possible variation of constants as violation of LTI. However, that is not correct.

We should acknowledge that there are two basic possibilities of variations of constants. One is a result of certain violation of LPI, while the other is an observational effect of the interaction with environment, such as the bath of Cosmic Microwave Background (CMB) radiation of photons, neutrinos, gravitons, Dark Matter (DM), matter etc.

The idea of scaling of the environment is changing once we increase accuracy. For example, we can say that the Earth gravity at accuracy better than one-ppm level is described by three forces: attraction by Earth, Sun and Moon and the acceleration of free fall, g, is a parameter of the interaction with Earth only. Alternatively, we can say that the complete gravitational force is always mg and it is varying in time because of the relative motion of Earth, Sun and Moon. That is not only a matter of definition. It depends on natural time scale of the experiment with respect to the periods of Earth motion and on whether we understand the planetary motion properly.

Interactions with the environment can always have a slow component, which is in a way universal. From the observational point of view a slowly changing parameter presents a kind of variation of a constant, but indeed that is not violation of LTI.

As a matter of fact, we have to acknowledge that the most popular model of evolution of the universe suggests so-called inflation [1] which is caused by a phase transition. The latter is a transition between two phases of vacuum. In the former phase the electron mass was zero and the proton mass was approximately 5-10% lower than now.

Another example of conceptual problems is the electric dipole moment (EDM) of an electron. The EDM of an electron can be caused by two effects. One is some violation of the CP invariance in one or other way, which allows a correlation between directions of a vector (the EDM) and a pseudovector (the spin, $\mathbf{s}$). All experiments have been interpreted in such a way. Meanwhile, there is another opportunity due to a possible violation of the Lorentz

[1]Theoretically, LTI is indeed a part of LPI, but from the experimental point of view the related experiments are completely different.

invariance. Such a violation can deliver a preferred frame (e.g., related either to the isotropy in CMB or to the local DM motion) and a preferred direction related to our velocity $\mathbf{v}$ with respect to the preferred frame. The violation could induce a certain EDM directed with this preferred direction (along $\mathbf{v}$) or in a direction of $[\mathbf{v}\times\mathbf{s}]$. All the experiments have been treated in the former way, while their results were considered as a model-independent limitation on the electron's EDM.

2 Variation of constants

Here we consider various aspects of a possible interpretation of experiments on variation of constants.

2.1 Can constants vary?

First of all, we note that the very motto 'variation of constants' is a jargon which is not related to reality. In a sense, the constants cannot vary, because the idea of variation of the constants is based on an assumption, that we can apply conventional equations, but claim that some their parameters are now adiabatically time- or space- dependent. That cannot be correct. We should completely change the equations.

Let us show a simple example why we should. Consider a quite unrealistic problem: a free electron in rest and the Planck constant changing in time ($\hbar = \hbar(t)$), but not in space in a particular frame. That is an isotropic situation and the angular moment L_z is conserved. On the other hand, it is equal to $\pm(1/2)\hbar(t)$. Something should be changed. Applying conventional equations of quantum mechanics to physics with changing $\hbar$ produces an obvious contradiction. Another example is considered in Sect. 2.6.

2.2 Alternating the basic description

At present, we have many equivalent ways to describe quantum mechanics. Introduction of the 'varying constants' into these different descriptions produces different effects.

For example, even in classical mechanics we have equations (like Newton's) and the variational principle of the least action. If we introduced something similar to varying constants into the Lagrangian we will change

the equations. Similar dilemma exists in quantum theory, where we should decide what the fundamental description is and what its consequences are.

We believe [2] that the fundamental original description is the Feynman's continual integral in quantum field theory [3] (which is similar to the path integral in quantum mechanics).

Indeed, this integral is not well-defined, but it reproduces the very soul of the quantum physics—the interference as its backbone. When we do experiments, like the famous Young's double-slit experiment, we look for an interference pattern. When Bohr first created a theory of the hydrogen atom, he was also dealing with interference effects such as standing waves. The Schrödinger equation has taught us that relation for a photon $E = \hbar\omega$ has deep meaning and in a sense any energy (at least for a stationary problem) is certain frequency because the stationarity is supported by a periodic motion and a resulting standing wave. Having in mind the path integral, we see that a stationary motion survives because of constructive interference after going the same loop again and again, while for any other frequency the interference is destructive. The Borh's orbit is a kind of a standing wave. The least action principle (the least distance Ferma principle for light) is also understood via a constructive interference—the phase around the least phase trajectory is almost not changing and that greatly enhances the classical trajectory by the summation of the huge number of very close trajectories, while far away from it the phase has no minimum and changes linearly with the variation of any parameter of the trajectory. The fast oscillating sum goes down because of destructive interference of nearby trajectories.

To our mind the most natural way to go beyond conventional physics phenomenologically is to change the phases in the continual integral (which is the action) and to derive proper equations from it.

Note, that to introduce medium into the Maxwell equation one has to change the electromagnetic Lagrangian in a relatively easy way (and that is related to a simple change in the action), while the derived equations already involve various complications such as derivatives.

2.3 Gradient terms

We need to emphasize that we deal with a phenomenological description and do not discuss how various time- and space-dependent factors can appear in the Lagrangian. We just like to describe a proper framework for the interpretation of the data.

Introducing time- or space-dependent factors into the Lagrangian we should expect their appearance in equations together with their gradients. In principle, some gradients could appear even in the Lagrangian. Once we have a derivative such as $\partial Y/\partial x_0$, where $x_0 = ct$ and $c = c(x)$, we have to think which of many ways should be taken to modify the derivative:

$$\begin{aligned} \frac{\partial Y}{\partial x_0} &\rightarrow \frac{1}{c}\frac{\partial Y}{\partial t}\,, \\ \frac{\partial Y}{\partial x_0} &\rightarrow \frac{\partial Y}{\partial (ct)}\,, \\ \frac{\partial Y}{\partial x_0} &\rightarrow \frac{\partial 1}{\partial t}\frac{Y}{c}\,, \end{aligned}$$

with some of them including the derivative $\partial c/\partial t$. But even if the Lagrangian in proper variables is free of derivatives, the equations of motion derived from the Lagrangian should contain some gradients.

Indeed, we should not be surprised by appearance of the time- and/or space-gradients. We have a well-known self-consistent example of a violation of the relativistic invariance with the speed of light depending in principle on frame, location, time etc. That is electrodynamics in media with a proper medium density. When we consider it in a conventional way, four three-dimensional field vectors have to be applied: **E**, **D**, **B** and **H**. If we consider that as a theory of photons, we should introduce, instead of the four former field vectors, one four-dimensional vector A_μ. When presenting all the equations in such a way, we immediately arrive at equations which contain not only two functions $\epsilon(x)$ and $\mu(x)$ (or even two tensor functions in a general case) but also their derivatives. If afterwards we will try to describe the complete interaction of two moving charges, their interaction should also include the derivatives of $\epsilon(x)$ and $\mu(x)$. That is far different from the naive expectation that it is enough to write $c(x)$ instead of c for the Lorentz force.

2.4 Dimensional quantities

Presence of the gradient terms allows to search for possible variations related to dimensional quantities. However, even without any gradient terms present in the basic equations, a variation of dimensional quantities can be detected.

Any measurement is a comparison and we have to deal with a 'measured value' and a 'reference value' of the same dimension. However, applying some

differential methods, a key comparison can be performed between two values of the same quantity, e.g., the speed of light, related to different directions. In other words, we can look for a relative change of a certain dimensional quantity.

Note that such a statement is related not only to fundamental physics, but also to practical issues. For example, the definition of the kilogram states that the mass of the prototype is exactly one kilogram. However, that does not mean that the mass of the prototype is not changing. A change in the mass of a particular object can be determined without any definition of the units. That can be done in relative units and only needs definitions of the involved quantities. Meanwhile, the definition of the kilogram fixes only the numerical value of the mass of the prototype, while the unit can change and that is detectable.

2.5 Three kinds of searches

Returning to possible variation of the constants, we conclude that there are three basic kinds of searches [2], which are

- a series of 'fast' measurements with 'long' separation periods;
- a 'long' monitoring experiment;
- a selectively sensitive 'gradient experiment'.

Selective 'gradient experiments' are model-dependent. They assume a certain possible effect and look for it. That may be a search for a gradient term, or a differential experiment. Indeed, to isolate a particular effect one should have a model and thus all such gradient terms are model-dependent and the dependence sometimes goes much further than expected naively. Due to the Lorentz invariance somewhat below the famous Michelson-Morley experiment is discussed as an experiment of this kind.

Most of the experiments are of a different kind: they look for certain values and check whether they change or not. However, a crucial point is duration of different phases of the experiment. In principle, there are two phases: reading the values (the measurement proper) and the accumulation of the effect of the variation (during a separation between the measurements).

The problem is that the accumulation period for a change of parameters of a system, like, e.g., the electron's mass and charge, usually does not involve

any effects of the gradient terms. The latter are important only during the measurements. If the measurement[2] is fast enough, the effects of the gradients can be neglected and the most important effect is the evolution of the parameters of the system under study between the measurements, namely during the accumulation time. In this case we can consider the same equations but with varying parameters and do a model-independent evaluation. A typical example of such kind of experiments is a study of the variability of the constants by means of atomic physics. Since the gradient are not involved the constraint can be achieved in such experiments only on variations of dimensionless quantities.

Another situation occurs for various space tests of general relativity and related experiments for $\partial G/\partial t$. The accumulation time and the reading-data time is essentially the same. Even if we try, similarly to atomic physics, to perform brief, say, one-day measurements every year, even that would not help. The problem is that when looking for a 'rotation' of an electron we cannot measure the phase of the rotation and deal with something related in sense of classical physics to average parameters of the orbital motion. The planetary motion allows us to look for the phase of the rotation and thus the 'coherence time' is equal to many periods of evolution. In a sense that is similar to the Ramsey method with two coherent space-separated short measurements. As a result, the effects of the gradients are of the same importance as effects of the time dependence of conventional terms. Any interpretation of the data in such a case is indeed strongly model-dependent.

Dealing with average values for planetary and atomic motion is also not the same. The atomic orbits are quantized. Their parameters do not depend on initial conditions, which determine only probability to create one or other atomic state. Planetary motion depends strongly on the initial conditions and thus even experiments on average values have a kind of history and accumulate effects from gradients.

Involvement of the gradient terms allows of constraining variations of dimensional constants.

[2]The measurements in sense of quantum mechanics is determined by the interaction time and by the coherence time. The measurement in sense of reading data consists of a session of many 'quantum measurements'. We indeed mean here the duration of the quantum measurements.

2.6 An example

Let us illustrate the consideration above with a clear example. We consider a case of a non-relativistic classical problem of a two-body system with one mass, M, much heavier than the other m (e.g., a Sun–planet, or planet–satellite system). We neglect all corrections in the order m/M and for further simplicity suggest a circular orbit.

The main parameters of the problem are: heavy mass M, lighter mass m, gravitation constant G, orbital radius R and orbital velocity v. Starting with the equation of motion in a conventional case (G, M and m do not depend on time) we find:

$$m\,\mathbf{a} = -\frac{GmM}{R^2}\,\frac{\mathbf{R}}{R}\;, \tag{1}$$

or

$$\mathbf{a} = -\frac{GM}{R^2}\,\frac{\mathbf{R}}{R}\;, \tag{2}$$

with appropriate initial conditions for a circular orbit.

If we assume that all the constants (G, M and m) depend on time, but expect that we can apply an adiabatic approximation, i.e., neglect all time derivatives, we can still use the equation of motion (1) or (2) and the lighter mass, m, vanishes there. That means in particular that any time dependence of m is unimportant, because for slow changes it looks natural to neglect all time gradients. In particular, measuring the distance R as a function of time we find

$$R = \frac{GM}{v^2}\;. \tag{3}$$

We note that the acceleration is orthogonal to the velocity and thus the velocity has only a tangential component ($v = v_{||}$) which is conserved. In other words, for time-depending terms we find a proportionality law

$$R(t) \sim G(t)\,M(t)\;. \tag{4}$$

However, the 'adiabatic approximation' is inconsistent. Let us consider the problem adiabatically, but neglecting the time-gradients in conservation laws, not in the equation of motion. As a result we find that (3) is still correct; however, the tangential velocity is not conserved. Instead, the tangential component of the momentum

$$p_{||} = mv_{||} \tag{5}$$

is. As a result we find

$$R = \frac{GMm^2}{p_{||}^2} \tag{6}$$

and for time-depending quantities the proportionality law takes the form

$$R(t) \sim G(t)\, M(t)\, \big(m(t)\big)^2 \tag{7}$$

to be compared with (4).

The difference between (4) and (7) is caused by a gradient term $\mathbf{v}\partial m/\partial t$ to appear in the equation of motion (1). In other words, adiabatic treatment of the conservation laws suggests a non-adiabatic approximation in the equation of motion. The example shows that the gradient terms in the equation of motions may be as important as adiabatic effects—the former lead to m^2 in (7), while the latter are responsible there for M.

The equations achieved above via the conservation laws do not contains gradients directly. Still they allow to constraint dimensional quantities. Technically that appears as a consequence of presence of certain dimensional conserved quantities, such as $p_{||}$ (as we demonstrated its conservation is related to a gradient term of the equation of motion). The dimensionless combination on which the constraint is achieved contains such a conserved quantity. Technically it originates from the initial conditions and that is why there is no analog of it in quantum theory where the atomic energy levels are determined only by the fundamental constants and not by any initial conditions.

One more point about this example is that the equation (7) cannot be the end of the story. In the framework given the mass should be conserved. There are two natural options to describe the time dependence of the mass and both imply further modifications of the scaling laws for $R(t)$.

The first idea is to allow a time dependence in the framework of classical non-relativistic physics. An obvious mechanism is to suggest that there is a mass in the space (e.g., dust particles) which is not observable and the very presence of this mass allows a change in the object moving through. This model is very similar to introducing, e.g., the internal (thermodynamic) energy into the mechanical consideration at the moment when it was absolutely unclear what the substance is. A similar successful idea was to suggest a neutrino to solve the problem of shortage of energy in the beta decay.

Suggesting such a mechanism solves the problem of a possible time dependence offering a mass transfer between unobservable dust and a moving body. Meanwhile, it opens a question of a possible transfer of momentum,

angular momentum and kinetic energy. Any particular model of the mass transfer sets constraints on the transfers of other quantities and will produce different corrections to (7). Note also that such a description will require the introduction of some functions to describe the dust particle in continuous space, i.e. to introduce a kind of fields (cf. Sect. 4).

Another possibility is to change the framework. For example, we can stop here to deal with non-relativistic physics and recall that it is energy rather than mass, which is conserved. However, in this case even before discussing any mechanisms of the energy transfer (which should be somewhat similar to the previous consideration) we have to acknowledge, that we should immediately change the basic equations of both kinematics (describing a motion of objects) and dynamics (describing the gravity).

In other words, we cannot simply say that the masses are time-dependent, we should go further to create a consistent construction which allows such dependence within a certain framework.

We have not discussed here two other problems. One is related to what can be really measured. When we look for a change in the distance, we usually mean that we look for a change in its numerical value in some units. The interpretation would strongly depend on what kind of clocks we use (the measurement of the distance is usually a measurement of light-propagation time) and on our assumptions on what can happen with the value of speed of light c.

The other question is the gravitational constant, whether it can change or we look for a variation of the masses only. To create a 'real' variation of G we need to modify theory of gravity. To make an 'observable' variation of G, it is sufficient either to change the units, or the masses, because we cannot observe G separately from gravitating masses and separately from measuring masses and distances or related quantities in certain units.

2.7 Variations of the constants and violation of the Lorentz invariance or LTI

When searching for a variation of constants one has to remember about a possible connection with various symmetries related to relativity.

The simplest issue is an observational one. The variations are long-term changes in values of fundamental constants, while a violation of Lorentz invariance could produce periodic effects because of the Earth rotation and

its motion around the Sun (more precisely both motions should be considered with respect to the remote stars[3]). That can be resolved experimentally.

The other issue is a reason for a variation of constants. There are basically three options.

- Variation of constants could be caused by 'long-range' environment. An example is the phase transition during the early time of the Universe. That has no relation to relativity.

- There is a certain dynamics directly in space-time continuum, which drives both: a violation of the relativity and a variation of the constants. An example could be a consideration of our 4-dimensional world as a result of compactification with the radius of compactification dynamically changing.

- An in-between option is a such kind of environment which affects some relativity issues naively understood. For instance, presence of a 'medium' does not violate the relativity once we speak about media as an non-fundamental issue added as an environment. Meanwhile, we can choose to consider theory with media as a fundamental 'quasifree' theory with broken relativity. What is important is the scale of phenomena. When we speak about the propagation of light and the interaction of classical macroscopic sources of the electric or magnetic field in a gas, we deal with a kind of fundamental electromagnetic theory with violated relativity. However, considering atomic spectra, we find that they are related to electrodynamics of vacuum and all deviations from the vacuum case happen on a certain macroscopic distance scale.

Indeed, only the second option is related to a violation of local position/time invariance.

[3]Even that is not absolutely clear. There are at least two preferred frames moving with respect to each other: one is related to the local DM cluster, while the other is related to the isotropic CMB. They suggest a different distance scale and both can in principle lead to periodic variations. Any periodic effect induced by the dark-matter-determined frame has no relation to a violation of the Lorentz invariance. With the CMB that is not clear. CMB proper is a kind of 'environment'. Meanwhile, if there is any fundamental violation of the Lorentz invariance, we would expect that violation determined the frame where the Big Bang happened and thus where the CMB is isotropic. So this frame is specific because of a possible violation and because of environmental effects, related to violations of the Lorentz invariance in the remote past

3 Planck scale physics in our low-energy world

3.1 Renormalization and Planck scale physics

A big success of quantum electrodynamics was due to the introduction of the renormalization scheme. Briefly speaking, quantum electrodynamics (QED) is in a sense not a fundamental theory, but a fundamental constraint.

A fundamental theory is such a theory that being formulated in terms of certain laws and certain parameters produces a result in terms of those fundamental parameters. Such a view on QED has failed because of divergences.

Indeed, in reality everything in physics should be finite, but we know that we possess only some knowledge on asymptotic low-energy behavior of various physical quantities. Very often applying asymptotics beyond their applicability one goes into unphysical behavior of various results and, sometimes, to divergences. To make divergences finite one has to use a complete description, not its asymptotics, with exact laws instead of their asymptotic forms.

The problem of QED is that we cannot learn anything about the 'complete description' and 'exact laws', because they are related to physics beyond our reach. Using different models for this physics (i.e. different regularizations) we arrive at different results.

Power of the renormalization procedure is in the treatment of QED as a fundamental constraint, not as a theory. We can calculate a long-range Coulomb-like interaction (which determines an observable value of the electric charge), we can study electron's kinetic (or complete) energy (which determines an observable value of the electron's mass) and we can measure a number of other properties such as the anomalous magnetic moment of an electron and the Lamb shift in the hydrogen atom. The 'constraint' means that they are correlated and we can calculate the correlation. Learning some of these values from experiment, we can predict the others.

The 'fundamental constraint' means that it is enough to learn very few values to predict all the others with an arbitrary accuracy (or more precisely—as accurate as we can treat them as pure QED values). For QED predictions, as we know, it is sufficient to measure the elementary charge and masses of each kind of particles.

The alternatives are known—to predict a value of the electric or magnetic field of a non-elementary object we have to know not only its charge and mass,

but also all details of the distribution of its electric and magnetic moments (and a number of parameters beyond that). Those details should be also measured. So we need an infinite number of the parameters.

Does the renormalization mean that the Planck scale does not contribute to our experiments? No, it does not mean that. The Planck scale indeed contributes, but it does not contribute to the constraint, because it only affects values of masses and charges, but we do not calculate, but measure them. That makes the Planck-scale effects unobservable. To observe we should compare a measurement and a calculation, but we have only results of measurements. However, there is an option when we should be able to see some effects of the Planck scale [2]. That is a case when we have certain dynamic effects at the Planck scale (e.g., a variation of some constants) or some violation of symmetries which would make our low-energy picture wrong.

For instance, if we assume that we live in a multidimensional world with a changing compactification radius, we may expect that electron's mass and charge should vary. The effects depend on the model of origin of bare masses and coupling constants. The bare values can change or, alternatively, the bare values would stand unchanged, while the renormalization term would change.

As an illustration we recall that we can see a number of consequences of special relativity and quantum mechanics in non-relativistic macroscopic phenomena. For instance, with a precision achieved in the mass spectroscopy, we can see a non-conservation of the mass because of the binding energy. Various interferometers of the macroscopic scale prove that the trajectory is not a well-defined property. And so on.

3.2 The classical Michelson-Morley experiment and calculability of the fine structure constant

Here, we consider as an example a possible problem with an interpretation of a classical version of the Michelson-Morley experiment. In the experiment some pieces of bulk matter were rotated. It was expected that when rotating their linear scale would not change and comparing the light propagation in different arms of the interferometer we can judge whether the speed of light is the same in different directions.

Meanwhile, there is no just 'speed of light' if we assume a violation of the

relativity. There are many different effects instead. But still we can expect that non-relativistic physics would not change too much. The size of a piece of atomic bulk matter is basically determined by the non-relativistic Coulomb interaction and we can believe that comparing a non-relativistic distance and relativistic propagation of light we should have a clear signature.

However, that is not that simple. The non-relativistic size depends on the electron mass and its charge. Let us, e.g., assume that α is calculable and that means that elementary charge can be presented in terms of $\hbar c$. If special relativity is violated and, e.g., $c = c(x)$, we should also arrive at $e(x)$. (More precisely, we should speak about calculability of the non-relativistic long-distance interaction of two charges *ab initio*.) The Coulomb interaction, which is a pure non-relativistic effect, would nevertheless be sensitive to a violation of the special relativity. Rotating the interferometer built as a bulk body we would deal with two effects: changes in speed of propagation of light and in a distance between the mirrors.

In other words, if the elementary charge is a fundamental quantity which is not correlated with the speed of light, the Coulomb-law energy is $E = Z_1 Z_2 e^2/r$ with possibly $e = e(t)$, while if α is calculable, it is $E = Z_1 Z_2 \alpha \hbar c/r$ with $\alpha = \alpha(t)$. (We remind that a real picture should be somewhat more complicated—instead of varying constants we should introduce some additional parameters and their derivatives (see above)).

In a more complicated way similar reasons can be related to masses of an electron and nucleon. The complicity is because we rather expect that α, if calculable, is calculable in a kind of one-step action (with further renormalization), while for masses we need to go step by step. For instance, for the electron we should first understand the calculability of parameters of the Higgs sector.

That means that for a proper interpretation of a Michelson-Morley-like experiment with an interferometer built on an atomic bulk matter we need to consider a dynamic model of structure of this kind of matter with a possible violation of relativity. The latter may involve the Planck scale effects, where a certain relation on low-energy fundamental constants can be set.

3.3 How to violate symmetries?

There is a number of ways to violate some symmetries. The most naive way it to violate such a symmetry directly. For example, the masses of the up and down quarks violate a chiral symmetry of QCD. That is the most

natural way for classical physics. In the case of quantum field theory, such a violation for the relativity and related effects can most likely take form of an external field (see Sect. 4 below). In particular, the spontaneous breakdown of symmetries takes the form of certain external fields.

Quantum theory also opens a number of other options (see, e.g., [2]). One of them is a so called anomaly. The violating term is a purely quantum effect proportional to $\hbar$. It appears because of singularities in original theory. While in the classical case the theory is symmetrical under a number of transformations, it is not possible to regularize all singular operators to keep all classical symmetries. Some of them have to be violated in the quantum-field case. The most well-known example is a so called axial anomaly, which violates chiral symmetry even for massless quarks.

A very remote analogy is conservation laws in classical and quantum physics. Description of quantum mechanics in terms of classical mechanics is not well defined, which happens because of commutativity of classical values and non-commutativity of their quantum analogs. We should regularize it and as a result part of classical symmetries may be realized in such a way that some conservation laws cannot be measured at all (e.g., conservation of the angular momentum as a vector). That example turns our attention to problem of observations.

Some effects may be a pure observational problem. We can illustrate it by comparing conservations in classical and quantum physics. We remark that we cannot check any conservation laws, but only their consequences. From the point of view of classical physics we expect that we can measure different components of angular momentum and check at some time whether they have the same values. From quantum physics we know that they would not have the same value and that we can directly check only conservation of one component of the angular momentum. Conservation of the angular momentum as a vector can be checked via some consequences, but not directly.

The problem is with commutations of different components of the angular momentum. Meanwhile, it is expected that operators of coordinates can be not-commutative in the quantum gravity. That would produce certain observational effects for naive tests.

4 External fields and related effects

4.1 External field as a violation of relativity and CPT

Even considering various violations, we basically expect that the relativity, CPT and many other would-be violated invariances are still present in a sense. Their violations used to be suggested in the form of a kind of external field of a classical (caused by matter or dark matter) or quantum (condensate) origin. We refer here to such a field as a 'violating field'. The violating field can have a certain simple form in a specific frame and the result in other frames can be found by an appropriate Lorentz transformation.

It is very natural that most of such violating fields are very similar to conventional fields such as scalar, electromagnetic, gravitational etc. That is not a surprise, because if we like to introduce both conventional and violating fields, we start from designing a certain interacting term in the Lagrangian which obeys all necessary symmetries. There are two basic differences between 'true' fields, which we used to deal with, and violating ones. The former are somewhat universally coupled to many objects and they are a result of certain sources existing in the case, or they are quantized as photons. The violating fields have no sources, they are background fields; and what is very important they are somewhat selectively coupled to other objects. We know only one kind of such a field, the Higgs field, which violates SU(2)$\times$U(1) symmetry in the Stardard Model of the electroweak interactions. It is also not-universally coupled to the matter fields and as a result the masses of charged leptons and quarks are all very different.

Let us also remind that a violation of CPT, most wanted by experimentalists, is such a violation when mass and charge of particle and antiparticle are not the same. To provide the different charges would be a big problem, since it assumes a non-conservation of the charge by producing a pair of particle and antiparticle (the alternative is a photon with a very small but not vanishing charge which is also not good). Possessing different masses means, that while the mass of an electron is

$$m_- = m - \delta m \;,$$

the positron mass is

$$m_+ = m + \delta m \;.$$

However, the same effects can be obtained if we assume that

$$m_q = m + qeU \;,$$

where q is charge, equal to ∓ 1, and the electric potential U is defined as $U = \delta m/e$.

Meanwhile, because of the gauge invariance we cannot observe any constant homogenous potential since the related strength of the electric field is zero. Does it mean that such a term is not observable at all? The answer depends on how we treat different particles and what kind of problem we study. If, e.g., we consider the muon in the same way, but if two effective potentials are not the same ($U_e \neq U_\mu$), we should be able to observe their difference. The decay of muon and antimuon should have slightly different kinematics and the difference in their lifetime caused by the different phase volume of the decay product, would be proportional to $U_e - U_\mu$. To understand that we can have in mind so unrealistically large value of this difference that a muon would decay, but an antimuon would not.

If we do parametrization more rigorously and introduce γ_0, instead of q (or more correctly to deal with the substitute

$$m \to m + \gamma^\mu a_\mu \ ,$$

where a_μ is a time-like vector), the result remains the same. An observable departure from CPT should be proportional to a certain difference of parameters of two particles, involved into calculations (cf. contributions of the a term in [4]).

4.2 'Selective' external fields and macroscopic experiment

As we could see above, the violating term is similar to the electric potential, but it is a kind of a selective field which should interact differently with different kinds of particles and only the differences can be observed.

A situation when the searched violating external fields are similar to conventional electromagnetic fields, but to selective ones, is very important from a practical point of view.

What is an electromagnetic field from a pragmatic point of view? In conventional electrodynamics an electron, a proton, a muon etc. sees the same electric field (once we neglect motional magnetic effects). If we set a different background field for different particles, that may well serve for producing a CPT violation or violation of the Lorentz invariance. The conventional magnetic field interacts universally with moving charges and there

is an additional interaction with spins or rather with related magnetic moments. Some of spin magnetic moments are calculable *ab initio* as for an electron or a muon, some should be treated phenomenologically, as for a proton or a neutron.

Meanwhile, any experimental setup involves macroscopic bodies, which can interact with the electromagnetic field, and some of them do interact. Certain substances do that in peculiar ways, when only one kind of universal interactions is involved.

For example, the solid conductors screen the 'true' electric field via a rearrangement of the electron density. With a violating field, which interacts with the electrons, added, the conductors should screen the field as seen by their electrons, i.e. they screen both 'true' electric field and the additional field interacting with electrons. As a result they leave a certain electric field inside the screened area. If the probe particle will be an electron, no field would be seen, because the remaining electric field will compensate the violating field. If the probe particle is a proton, it should see a certain effective field which is a difference of violating proton's and electron's fields.

A similar situation is with a magnetic-field-like violating field. The 'true' magnetic field interacts universally with all particles and the same field is seen by any orbital and spin magnetic moments in a consistent way. The violating field could be different for different particles and it may interact in a different way with the spin and the orbital motion. Some magnetic screening materials act via a production of certain electron currents (i.e., the orbital motion), while others via a rearrangement of the electron spins. While providing the screening, the electrons will act in such a way that they will cancel all the field, including a violating component.

These examples show that while there may be certain vacuum effects, the experiments are never done in vacuum. A certain screening is always needed to avoid residual electromagnetic fields. In the case of CPT violating fields, acting as 'selective' electromagnetic fields, a certain electron-interacting component of such a field should be compensated by an electromagnetic field created by the shielding material. That should be taken into account for interpretation of such experiments.

5 Microscopic and macroscopic description

While a natural microscopic picture involves an effective external field, the natural macroscopic description is rather a kind of dilute medium (e.g., for the dark matter) which weakly interacts with light etc. It is not the ether! The dilute medium obviously affects the Doppler effect etc. and produces a signal for the Michelson-Morley experiment. The speed of light would not be a universal 'c'. However, for microscopic properties such as a value of mc^2 as the rest energy that would be different. Either they would have no relation to measured velocity of light in the media, or there would be different changes.

For example, considering the time dilation of the lifetime of an unstable nuclear level we should consider the nucleus which lifetime changes because of two different effects: conventional Lorentz transformation and interaction with the dilute media particle. The same should be with various ratios of different transition frequencies from the same atom.

Indeed, the particle interaction with the dilute media depends on their relative velocity but also on various other parameters. E.g., we can assume that the particle directly interacts with the (dark-matter) medium (via a heavy intermediate boson) and the interaction with light is indirect and somewhat weaker. Or on the contrary we can suggest that the dilute medium is weakly coupled to the light directly and any interaction to the other matter is an induced effect. Indeed, with a fixed value of the light-media interaction, the effects of matter-media interaction can easily vary by orders of magnitude.

The crucial point here is a possible scale of the effects. The Michelson-Morley experiment and some others are of macroscopic nature and they can check various symmetries on a large scale with respect to atomic and particle effects scale. The latter scale could be studied via a different kind of experiments and it is not necessary that the result be consistent.

Addressing different scales of times and distances we study a part of effects and trying to generalize the results may do some model-dependent suggestions.

6 Summary

Above we have demonstrated that looking for some new physics and in particular for possible violations of some symmetries it is hard to avoid certain model dependence which may sometimes produce a misleading interpreta-

tion. It is hard to give any general advices except for being careful.

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